Natural Gas Vehicle Technology Forum
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Biogas to LNG

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The challenge to create an economical LNG & CNG refueling infrastructure for a transition to NG in the transportation sector

- How do we achieve 10 % penetration into transportation sector by 2020?
- ~100 quads/year in US with ~25 % of total for transportation
- ~25 quad/1000 Btu/scf for NG is ~ 25 x 10^{12} scf/year
- ~25 x 10^{12} scf/year/82.6 scf/gallon of LNG is ~ 3 x 10^{11} gallons LNG/year or ~ 830 MM gpd of LNG
- ~830 MM gpd/~200,000 stations is ~ 4,150 gpd LNG/station
- Average stations match 'distributed-scale purifier/liquefier technology' for PNG to LNG/LCNG modular systems with ~5,000 gpd capacity; also supply via tanker and have CCNG as desired
- For 10 %, install ~20,000 stations at ~$0.5-1.0 MM/station over ten years is ~$1-2 billion/year investment required – with innovative, robust facility packaging
- Gross revenues from LNG/LCNG sales at 20,000 stations are significant; ~83 MM gpd at ~ $1/gallon is ~ $83 million/day or ~$30 billion/year.

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The transportation sector is simultaneously a great challenge and a great opportunity

- Our strategic technology development is to make cost-effective technology at distributed-scale sizes to produce LNG that is ‘all-in’ priced to compete at a price discount against diesel and gasoline
  - ~0.5 MMscfd to ~2.5 MMscfd of methane as LNG or LCNG or CCNG
  - In the early 1990’s no distributed-scale purifiers/liquefiers making ~5,000 gpd of LNG from ~0.5 MMscfd of PNG were available other than custom orders
  - Most utilities were not interested in PNG to LNG for transportation sector
  - Most good, proven large and medium-scale technologies for methane purification and liquefaction did not cost effectively scale down to this capacity
- During last 15 years we have made numerous improvements to existing technology and created several innovations related to purification & liquefaction
  - Several lab-scale to complete industrial plants have been designed, built, tested, installed and slowly but successfully commissioned and operated – great experience!

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The Prometheus business model evolved from demand side to waste or stranded source supply side

Sourcing → **Production** → **Distribution**

Coal-mine methane

Landfill biogas

Stranded well gas

Digester biogas

Vehicle fuel

Industrial usage

Remote communities

Peak shaving

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Example at Frank R. Bowerman Landfill

- Located in Orange County, CA
- Landfill is owned/operated by Orange County Integrated Waste Management Department
- Landfill site is 725 acres
- Max permitted daily acceptance rate is 8,500 tonnes/day
- >10 million standard cubic feet of LFG is flared each day

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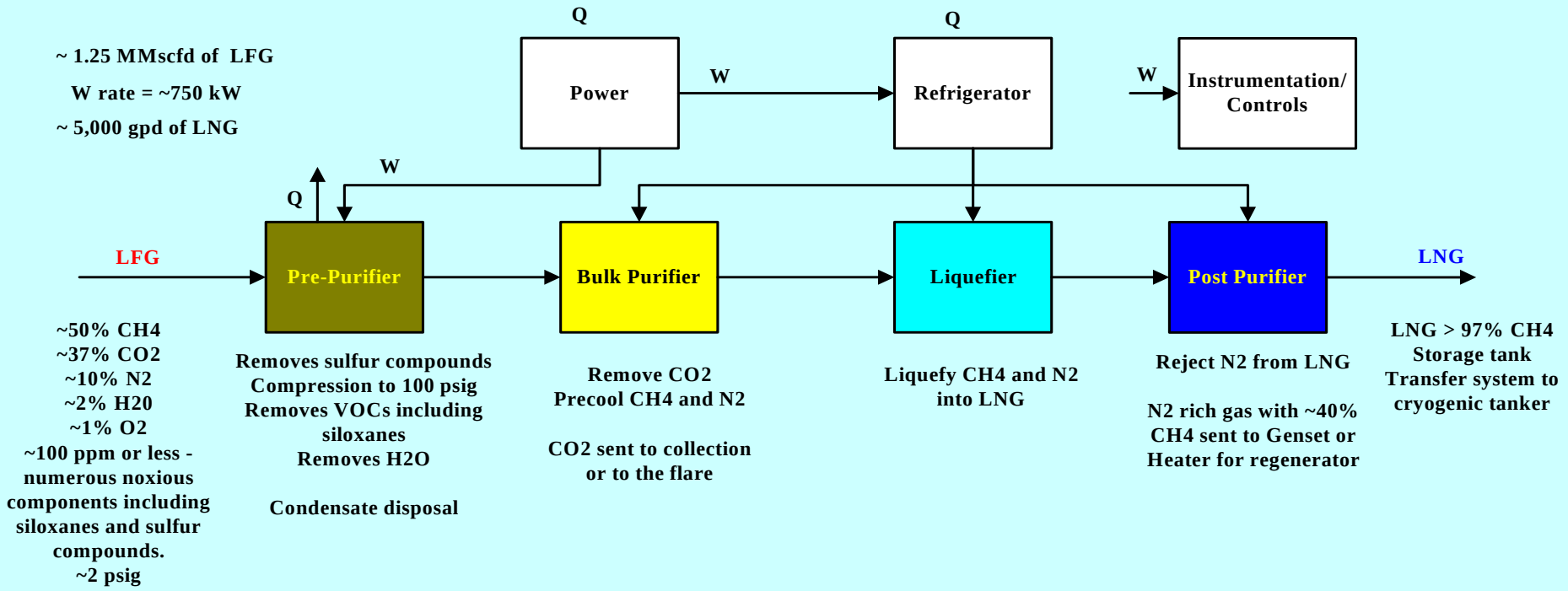
Our facility at Bowerman Landfill is an excellent beta site that provides a great basis for commercial LFG-to-LNG projects



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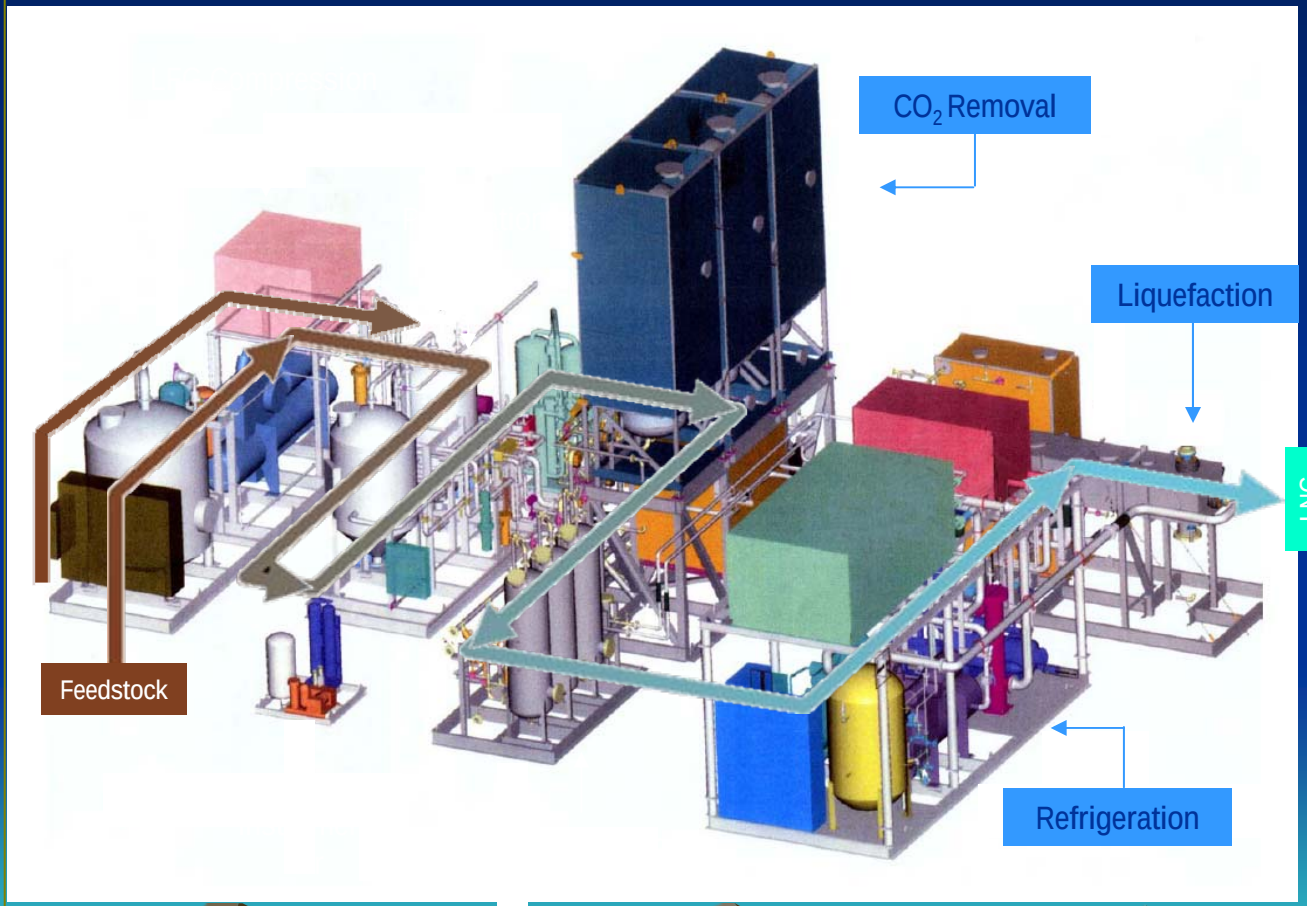
Prometheus' purification and liquefaction technology has been tested/improved by converting LFG to LNG

Illustrative facility



Prometheus' Competitive Advantages

- Proprietary small-scale purification and liquefaction technology
- Scalable modular design enables rapid and portable deployment
- Integrated purification and liquefaction system leads to higher efficiency and lower power requirements

Proprietary / Unique Technology

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The Bowerman beta-site distributed-scale design integrated several modules for higher efficiency. To date it has produced ~400,000 gallons of high quality LNG from LFG

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Cryogenic tankers at Bowerman for LNG delivery into increasing local fuel market demand

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Biogas feedstock is comparable to LFG and will provide high quality LNG

- LFG specs
  - 50 ± 5 % CH_4
  - 35 ± 5 % CO_2
  - 10 ± 5 % N_2
  - 0.3 ± 0.5 % O_2
  - 300 ± 100 ppm_v H_2S
  - 1 ppb to 1 ppm VOCs & especially siloxanes
  - 2 ± 3 % H_2O
  - ~1 psig; ~65 °F
- Biogas specs
  - 65 ± 5 % CH_4
  - 35 ± 5 % CO_2
  - 1000 ppm_v N_2
  - 10 ppm O_2
  - 1000 ppm_v H_2S and other VOCs
  - No siloxanes
  - 2 ± 3 % H_2O
  - ~1 psig; ~90 °F

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Specifications of LNG from LFG or biogas

- LFG feedstock: >97 % CH_4 with residual primarily N_2
- Biogas feedstock: >99 % CH_4
- Multiple stages of purification driven by the very low solubility of most impurities in LNG
  - CO_2 will be below ~100 ppm
  - H_2O will be below ~ 1 ppm
  - Siloxanes, VOCs, H_2S will be ~ 1 to 100 ppb
- N_2, C_2H_6. C_3H_8 form a homogeneous mixture with LNG; weathering in reverse is an potential advantage, e.g. with N_2
- Increasing experience with cryogenic fuel handling and awareness of combustion with N_2 or CO_2 or H_2 on engine performance

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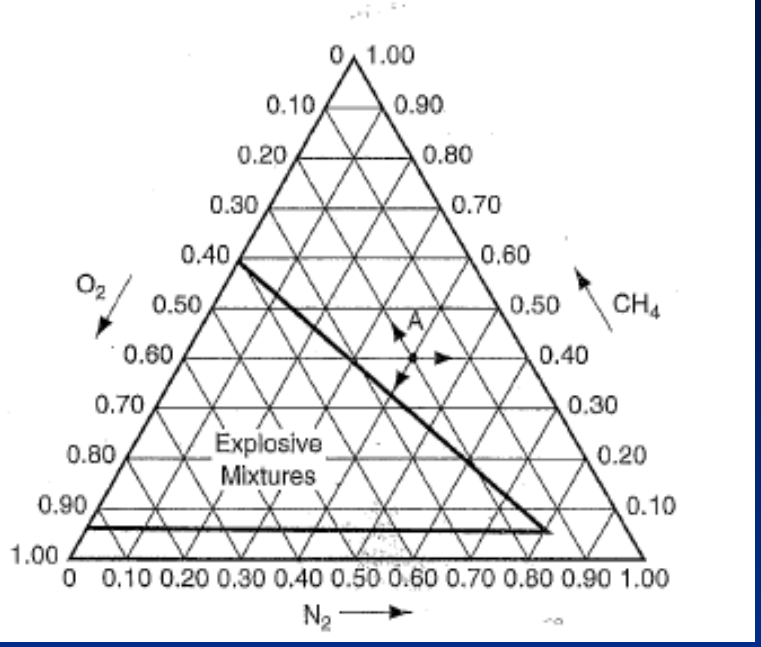
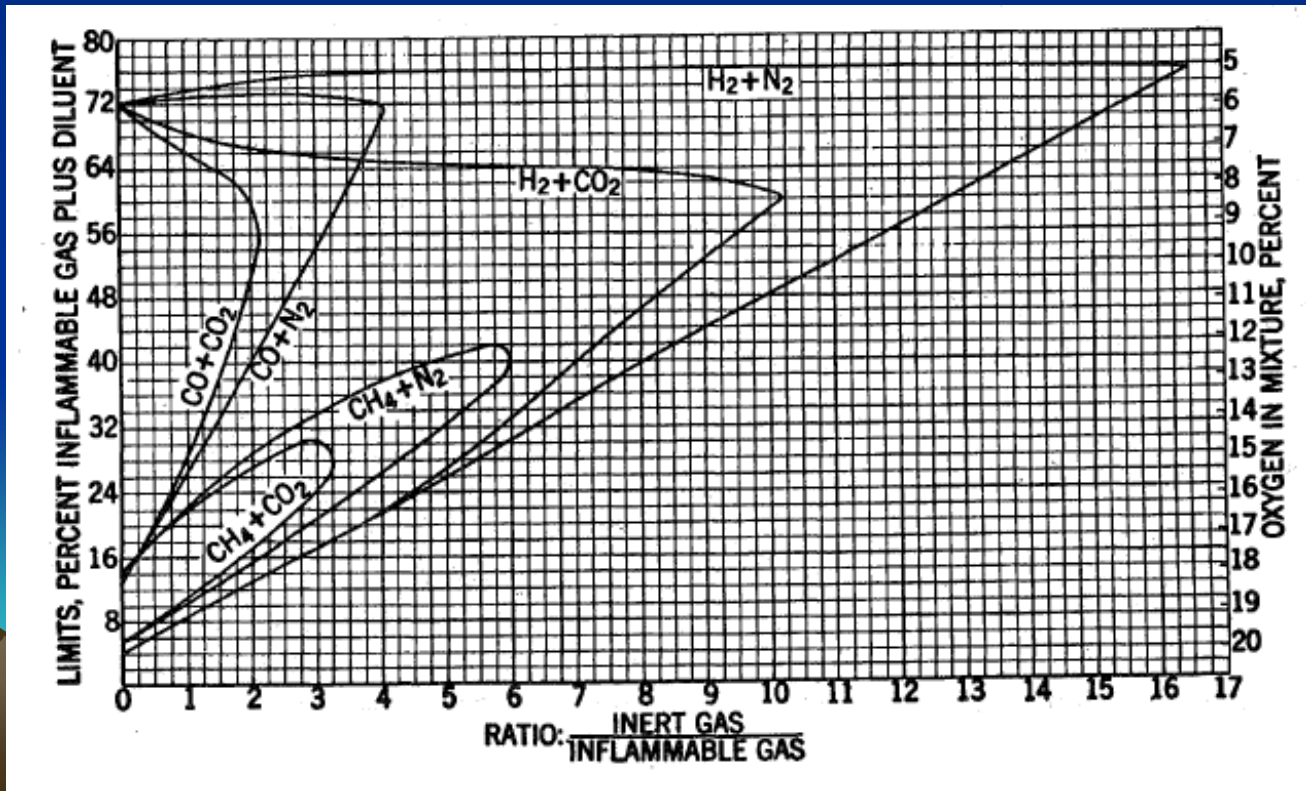
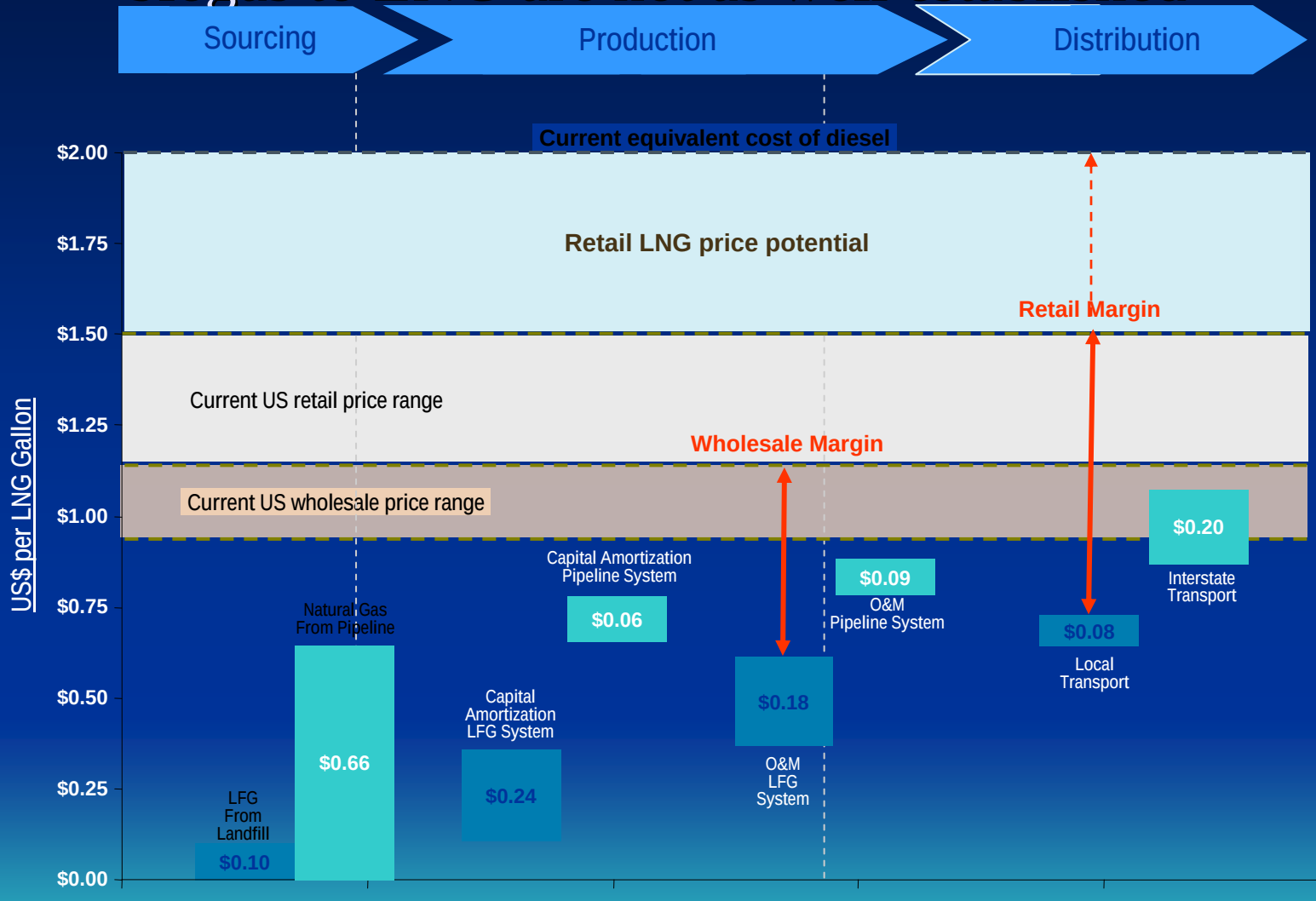


There are issues to be aware of – e.g. methane's flammability range changes with composition



The economics of LFG to LNG for vehicles are compelling; biogas to LNG are not as well established



Prometheus' competitive advantage secures low-cost source and customer proximity

(1) For illustration purposes - actual figures will vary from one project to another – assume Natural Gas price at $8.00/mmBtu

(2) Historically, LNG has been priced at a bargain to diesel, but there are now specific instances of price and margin increases as L... a more mainstream fuel for fleet users. Given the superior qualities of LNG over diesel, we expect this trend to continue.

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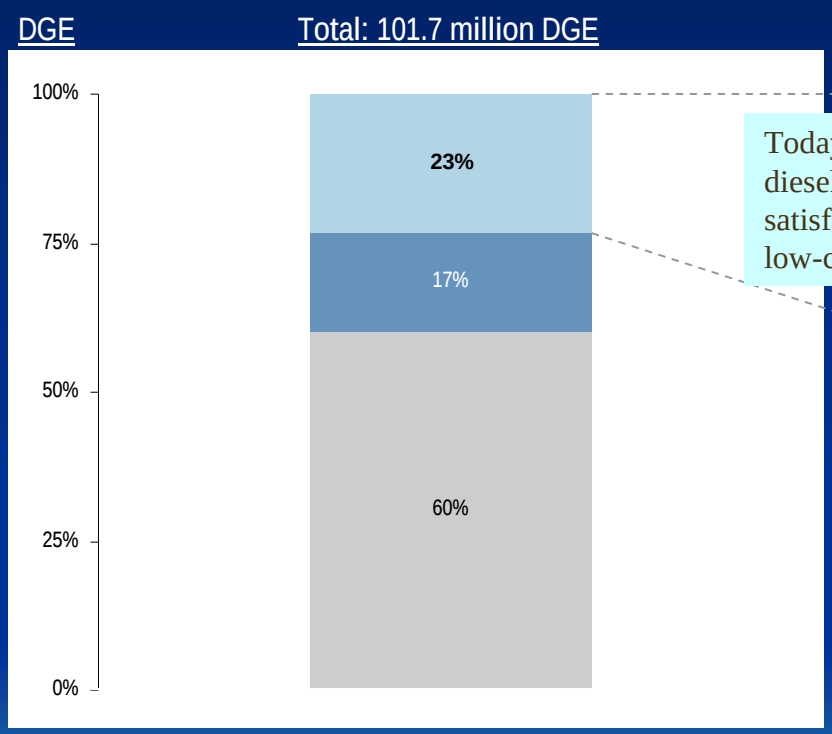
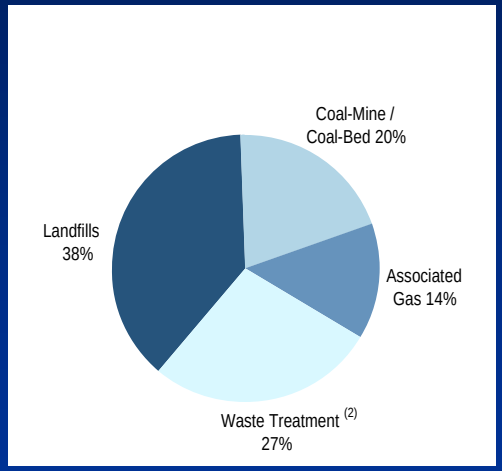
Potential LNG supply from waste methane resources in the US could have a significant impact(1)

Gas demand breakdown in the US (1)



Today almost ¼ of the US diesel demand could be satisfied by non traditional, low-cost gas sources of LNG



- Landfills alone stand for almost 40% of the whole potential LNG resources
- Coal-mine/Coal-bed represent 20%

(1) Source: EIA - Adjusted Sales For Transportation Use: distillate fuel oil and residual fuel oil, 2004
(2) Includes Waste Water and Manure Management

- LNG from "non-traditional" sources of methane, part of which is landfill gas
- LNG from pipeline and stranded well resources
- Remaining diesel demand

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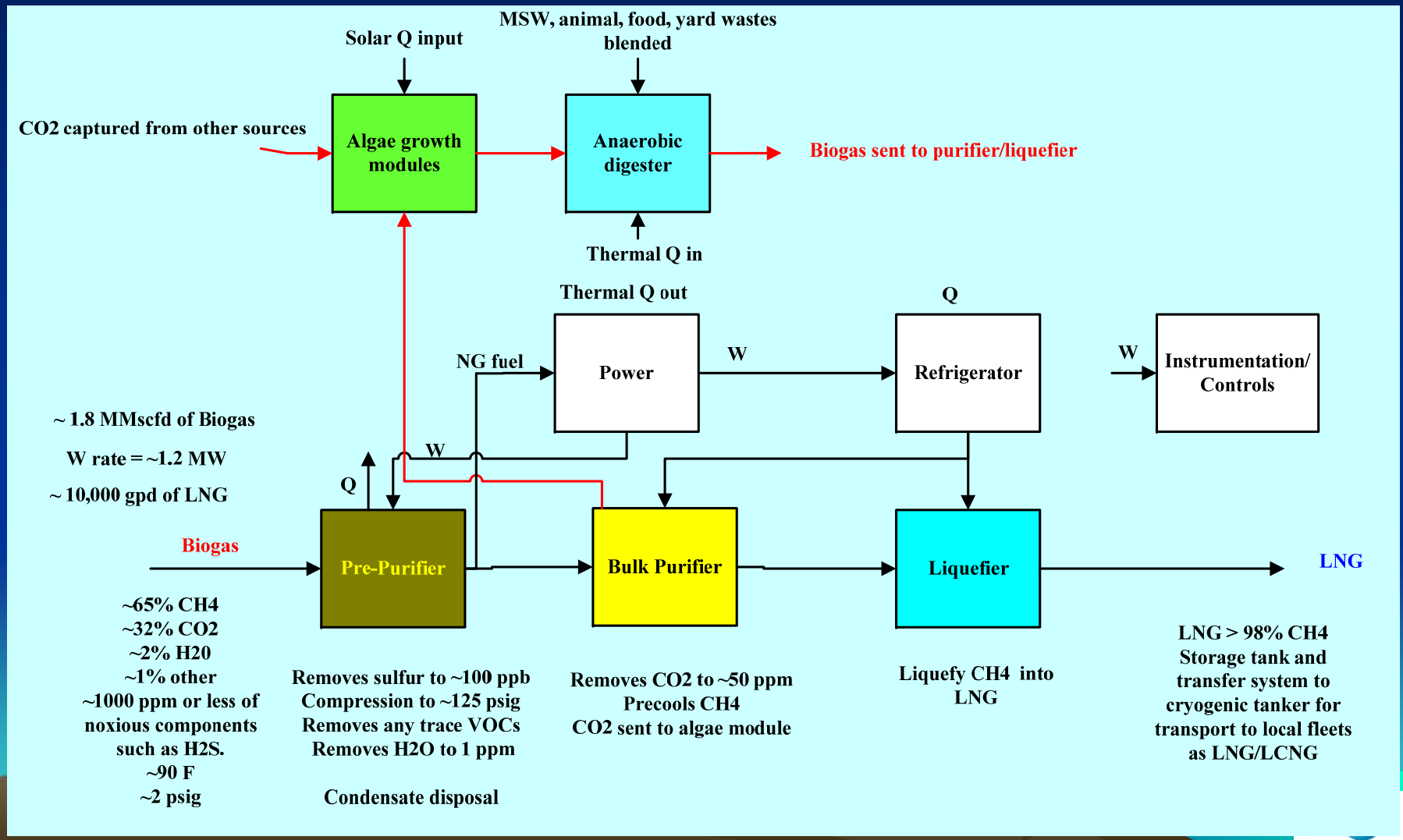
The ability to capture high grade CO_2 cryogenically, recycle it into biogas, and distributed-scale liquefaction provides an excellent sustainable, renewable source of LNG for fleets



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Summary

- Energy technologies for vehicles cross link economics, renewable fuel cycle, environment, waste, climate change, & carbon capture business sectors; continue to better understand these linkages!
- Economics strongly influence choices among practical vehicle fuels; encourage oil to go back to $100/bbl!
- LNG/LCNG/CCNG supply for the transportation sector is simultaneously a major challenge and a great business opportunity; investments require good returns with tolerable risks – fuel coops!
- Renewable methane coupled with CO_2 capture is a promising cost-competitive, environmentally-compatible, sustainable energy carrier; fund pilot-scale projects in multiple locations to work out the bugs!
- Educate on the need to develop high quality, efficient technology for methane and hydrogen that accelerates the adoption of renewable & sustainable energy systems.

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